(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 211 726 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
05.11.2003 Bulletin 2003/45

(51) Int Cl.[7]: **H01L 21/762**, H01L 27/12, G02B 26/08, B81B 3/00

(21) Application number: **01127729.0**

(22) Date of filing: **21.11.2001**

(54) **Single-crystal-silicon flexible ribbon for micro-mirror and MEMS assembly on silicon-on-insulator (SOI) material**

Band aus einkritallinem Silizium für Mikrospiegel und MEMS auf SOI Material

Ruban articulé en silicium monocristallin pour micro-miroir et MEMS sur matériau SOI

(84) Designated Contracting States:
DE FR GB

(30) Priority: **29.11.2000 US 724329**

(43) Date of publication of application:
05.06.2002 Bulletin 2002/23

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Printed by Jouve, 75001 PARIS (FR)

Description

Background of the Invention

[0001] The present invention is directed to micro-hinges used in micro-electromechanical systems (MEMS) and micro-systems technology, and more particularly to an improved micro-hinge configuration and design adding robustness and strength to the hinging element.

[0002] The use of micro-hinges has become prevalent with the increased utilization and complexity of surface micromachine components and systems. Typically used in the implementation of out-of-plane or vertically oriented micro-device designs, the micro-hinge is usually fabricated in a minimum two-layer, though typically three-layer, polysilicon process. Such a hinge, known as a staple hinge, is illustrated in FIGURE 1, integrally connected with micro-mirror 12, and is used to attain out-of-plane motion. The multi-step fabrication process, includes depositing a first layer which is then patterned and etched. Next a second layer is deposited, patterned and etched in such a way that after removing any filling material, the first layer is free to move in a prescribed path, while being held in place by the second layer. This structure creates a rotating joint implemented in MEMS or micro-systems to permit for the mechanical movement required for micro-mirrors and other out-of-plane devices.

[0003] Drawbacks to existing micro-hinge designs include process complexity and cost of fabrication.

[0004] The inventors have also observed that the device layer of silicon-on-insulators (SOI) wafers are being used to form micro-structures such as mirrors, lenses and other out-of-plane or vertically oriented devices for integrated MEMS and micro-systems. For example US 6 074 890 A discloses methods for fabricating single crystal silicon MEMS suspended on a SOI wafer structure optimising the ability to bend without fatiguing. The formation of such devices requires the use of micro-hinges to provide rotational freedom and mechanical support for these out-of-plane devices.

[0005] It is therefore considered useful to develop less complex and costly micro-hinges capable of providing the necessary mechanical integrity and strength to allow out-of-plane rotation or vertical movement of SOI device layer structures.

Summary of the Invention

[0006] Provided is a micro-assembly including a micro-device formed on a device layer of a single crystal silicon substrate. A ribbon structure is formed on the device layer, where the ribbon structure is thinned to a thickness which is less than the thickness of the micro-device. A connection interface provides a connection point between a first end of the micro-device and a first end of a ribbon structure, wherein the ribbon structure and micro-device are integrated as a single piece.

Brief Description of the Drawings

[0007]

FIGURE 1 is directed to a micro-mirrored device using multiple polysilicon layers for implementation of a micro-hinge;

FIGURE 2 is an isometric view of a ribbon hinge attached to an out-of-plane device according to the teachings of the present invention;

FIGURE 3 is a side view of the ribbon hinge and out-of-plane device of FIGURE 2;

FIGURE 4 sets forth the processing steps for formation of the ribbon structure attached to an out-of-plane device in accordance with the teachings of the present invention;

FIGURE 5 is an illustration for one design in accordance with the teachings of the present invention; and

FIGURE 6 illustrates an alternative embodiment of the present invention wherein the movement of the micro-mirrors is accomplished by an active operation.

Detailed Description of Preferred Embodiments

[0008] While Figure 1 depicts a micro-device implementing a polysilicon staple hinge, FIGURES 2 and 3 illustrate a micro-assembly 18 having a ribbon hinge 20 configured according to the present invention, in an integrated arrangement with a micro-device 22, such as a micro-mirror. The micro-device has been moved from an in-plane position to an angle of approximately 30°. Movement of the micro-device is achievable by a variety of mechanisms, including the use of a micro-probe or an actuator.

[0009] Ribbon hinge 20 is, therefore, designed to replace the widely used polysilicon staple-hinge design illustrated in FIGURE 1. Ribbon hinge 20 is a single-crystal-silicon (SCS) component which has mechanical stability, and which is configured using a simplified processing procedure. Thus, ribbon hinge 20 of the present invention provides a flexible mechanism as opposed to the jointed staple-hinge of FIGURE 1.

[0010] Ribbon hinge 20 is formed from the device layer of a silicon-on-insulator wafer, which has been thinned down to allow increased mechanical flexibility. This design produces a high quality mechanical structure having sufficient strength for its intended purpose.

[0011] FIGURES 2 and 3 emphasize the flexibility of ribbon hinge 20. In this embodiment, ribbon hinge 20 is approximately 500nm thick, approximately 50μm wide and approximately 140μm in length. Micro-device 18, including ribbon hinge 20 and mirror 22 is fabricated using a silicon-on-insulator (SOI) wafer with a device layer thickness of approximately 3μm and a buried oxide

(BOX) layer thickness of approximately 2μm.

[0012] In a two-mask process used to manufacture the micro-device 18, an area to be thinned is first lithographically exposed, and surrounding areas are protected, before a timed wet etch reduces the thickness of the exposed silicon area 20 to ~500nm. Then a subsequent lithography step is used to pattern the hinge 20 and mirror 22 areas exposing all surrounding areas to be etched. This leaves the mirror structure protected, by an oxide layer, and the thin silicon ribbon hinge resting on the sacrificial BOX layer. Following buried oxide removal using a Hydrofluoric Acid (HF) 49% etch process step and subsequent drying procedures, mirror 22 is freed to move.

[0013] As will be discussed in greater detail below, the present invention is a two-step process in the sense that in the first step the hinge area 20 is patterned and etched. Then a second procedure is used for lithographically defining and forming the mirror area 22 (or other out-of-plane or vertically oriented device). It is of course possible to inverse these processes by processing the out-of-plane device area first, then thinning the ribbon layer. An issue in this regard is that the out-of-plane device and ribbon hinge are all formed from the same material layer. The difference between the ribbon hinge and the out-of-plane device is the geometry of the patterning, and the physical thickness of the areas. Particularly, etching ribbon hinge 20 to a much thinner cross-section than the out-of-plane device, permits increased flexibility of the ribbon hinge. The flexibility of ribbon hinge 20 is illustrated by its almost S-shape (See Figure 3).

[0014] The methodology that incorporates fabrication of the ribbon hinge structure in the same material as the out-of-plane device such as the mirror, has many advantages over existing hinge technologies, including a simplified fabrication process. For example, since the hinge is fabricated using the same material layer as that of the out-of-plane device, there is no adhesive joint or holding structure necessary between the hinge and the attached device. Such a design accommodates the high mechanical torque and forces delivered by the attached mechanical device without comprising the integrity of connection point 24 between the hinge structure and the attached micro-device.

[0015] FIGURE 4 illustrates a process flow for fabrication of a single crystal silicon ribbon hinge according to the present invention. In step 28, the process begins with a clean silicon-on-insulator (SOI) wafer 30 having a single crystal silicon device layer 32, a buried oxide layer 34, and a substrate layer 36. In a first step of the process, 38, a photo-resist layer 40 is deposited on device layer 32 using standard lithographic processes. Photo-resist layer 40 is patterned in such a way as to expose the area to be thinned into the ribbon hinge 42. In a next step 44, a wet etching process is undertaken such as wet etching with a potassium-hydroxide (KOH) 45% solution at 60°C. The wet etching causes the exposed ribbon hinge area 42 of device layer 32 to be removed to a thickness of approximately 500nm.

[0016] In step 46, previously applied resist layer 40 is removed prior to a repatterning for etching of the out-of-plane device, an island area and an anchor structure. Following removal of first photo-resist layer 40, second resist layer 48 is applied on the top surface of SOI 30. In step 50, a dry etching process is undertaken on the exposed silicon of device layer 32 to form the out-of-plane device structure 52 as well as the island area 54 and anchor structure 56. In step 58, the second layer of photo-resist 48 has been removed, and an etching process is started to begin etching the exposed buried oxide layer 60, using a Hydrofluoric Acid (HF) 49% solution.

[0017] Next, in step 62, the third and final layer of photo-resist 64 is deposited and patterned on the SOI wafer 30. This final photo-resist layer 64 is to be used during the buried oxide-release (BOX) operation, wherein the out-of-plane device 52 is released by etching all unprotected buried oxide. This process is shown completed in step 66 where remaining buried oxide layer material 68 and 70 are located under the island structure 54 and under the anchor section 56. As can be seen in step 66, a separation layer 72 and separation edge 74 are shown as being void of material. Removal of the material in these areas allows for the movement of the out-of-plane device 52 and ribbon hinge 42 in a manner similar to that shown in FIGURES 2 and 3. In step 66, it is noted that all remaining photo-resist is removed, for example by a dry O_2 plasma-etch process. Thus, step 66 depicts the original SOI wafer 30 as a completed mirror and hinge structure.

[0018] Turning to FIGURE 5, set forth is an implementation of a passive micro-mirror assembly using the ribbon-hinge methodology of the present invention. Dual mirror device 80 illustrates that by application of the discussed manufacturing steps a SOI wafer can be processed into a micro-device incorporating multiple mirrors and hinges. A first ribbon hinge 82 is fabricated so as to be integrated to an anchor portion 84 at one end and to a movable mirror structure 86 at a second end. First, ribbon hinge 82 and anchor portion 84 are joined at connection point 88, and first ribbon hinge 82 and mirror 86 are joined at connection point 90. Thereafter, a second ribbon hinge 92 is connectably fabricated to mirror 86 at connection point 94 and further integrated to second mirror 96 at connection point 98. The mirrors and ribbon hinges of device 80 are fabricated in the same device layer of an SOI wafer.

[0019] Slots 100 may be formed in the same device layer as ribbon hinges 88, 92 and mirrors 86, 96. Slots 100 are formed in an area behind the mirrors outside of the area of the ribbon hinges, and are made to run along both sides of mirror 96 (only one side of slots 100 are shown for convenience) allowing balanced fixture of mirrors 86, 96. In such a passive design, mirrors 86, 96 are assembled using micro-probes, and once in place reside fixed and unaided. Particularly, as micro-probe (not shown) moves mirror 96 out of plane, the side edges

102 of mirror 96 may be placed into any one of slots of slot configuration 100.

[0020] Once placed within a slot, mirror 96 as well as mirror 86 is maintained in a fixed position. It is noted that the flexibility of the ribbon hinges 82 and 92 allow for flexing in opposite directions. For example, ribbon hinge 82 is shown flexed in a concave position whereas ribbon 92 is in a convex position.

[0021] FIGURE 6 sets forth an alternative microstructure 104 embodiment implementing ribbon hinges according to the present invention. Particularly, the movement of mirrors is obtained via active operation as opposed to passive, e.g. movement of the mirrors by a probe. A controllable element, such as a comb-drive actuator assembly 106 is attached to mirror 96 via ribbon hinge 108. Comb-drive assembly 106 includes interdigitated comb fingers 112, a drive shuttle 114, and suspension arms 116. The mirror angles are then dynamically adjusted by application of an applied voltage from a voltage source (not shown) which results in the displacement of the comb-drive assembly 106 and hence the attached devices. It is to be appreciated other active actuators may also be used to move out-of-plane devices in accordance with the present invention.

Claims

1. A micro-electromechanical assembly (MEM, 18) comprising:

an out-of-plane devices (22) formed in a single-crystal-silicon device layer of a silicon-on-insulator (SOI) substrate and;
a flexible ribbon structure (20) formed in the device layer, where the out-of-plane device (22) and ribbon structure (20) are formed as an integrated assembly.

2. The invention according to claim 1 wherein the device layer is formed as part of a silicon-on-insulator wafer, including at least the device layer and a buried oxide layer.

3. The invention according to claim 1 wherein the ribbon structure has at least one of a width or thickness which is less than at least one of a width or thickness of the out-of-plane device.

4. The invention according to claim 2 wherein the out-of-plane device is fabricated from a silicon-on-insulator wafer which has an initial uniform device layer thickness.

5. The invention according to claim 1 wherein the ribbon structure has a thickness of between approximately 400nm to 600nm, a width of between 25µm - 75µm, and a length of between 70µm and 210µm.

6. The invention according to claim 1 wherein the ribbon is configured with a mechanical integrity which permits application of a side-twisting mechanical torque to the out-of-plane device sufficient to twist the out-of-plane device to 90° or more from an initial 0° twisted position.

7. The invention according to claim 1 wherein the ribbon is configured with a mechanical integrity which permits application of a lifting out-of-plane mechanical torque to lift the out-of-plane device from 0° which is in the horizontal plane, to 90° or more out of the horizontal plane.

8. The invention according to claim 1 wherein the out-of-plane device is a micro-mirror.

9. The invention according to claim 1 wherein the ribbon is a micro-hinge.

10. The invention according to claim 2 wherein a second end of the ribbon structure is attached to an anchor point above the buried oxide layer, and a second end of the out-of-plane device is unattached to the buried oxide layer.

Patentansprüche

1. Mikroelektromechanische Einheit (MEM, 18), umfassend:

- eine ebenenverschobene Vorrichtung (22), geformt in einer Einkristallsilizium-Vorrichtungsschicht eines Silizium-auf-lsolator-(SOI)-Trägers; und
- eine flexible Bandstruktur (20), geformt in der Vorrichtungsschicht, wobei die ebenenverschobene Vorrichtung (22) und die Bandstruktur als integrierte Einheit geformt sind.

2. Erfindung nach Anspruch 1, wobei die Vorrichtungsschicht als Teil einer Siliziumauf-Isolator-Scheibe geformt ist, die wenigstens die Vorrichtungsschicht und eine vergrabene Oxidschicht umfasst.

3. Erfindung nach Anspruch 1, wobei die Bandstruktur wenigstens eine der Breite oder Dicke aufweist, die geringer ist als wenigstens eine der Breite oder Dikke der ebenenverschobenen Vorrichtung.

4. Erfindung nach Anspruch 2, wobei die ebenenverschobene Vorrichtung aus einer Silizium-auf-lsolator-Scheibe hergestellt wird, die eine anfängliche einheitliche Vorrichtungsschichtstärke aufweist.

5. Erfindung nach Anspruch 1, wobei die Bandstruktur eine Dicke zwischen etwa 400 nm und 600 nm, eine Breite zwischen 25 µm und 75 µm und eine Länge zwischen 70 µm und 210 µm aufweist.

6. Erfindung nach Anspruch 1, wobei das Band mit einer mechanischen Integrität angeordnet ist, die eine Anwendung eines seitenverdrehenden mechanischen Drehmoments auf die ebenenverschobene Vorrichtung gestattet, das ausreicht, um die ebenenverschobene Vorrichtung aus einer anfänglich um 0° verdrehten Position auf 90° oder mehr zu verdrehen.

7. Erfindung nach Anspruch 1, wobei das Band mit einer mechanischen Integrität angeordnet ist, die eine Anwendung eines anhebenden ebenenverschobenen mechanischen Drehmoments gestattet, um die ebenenverschobene Vorrichtung von 0°, was der horizontalen Ebene entspricht, auf 90° oder mehr aus der horizontalen Ebene zu heben.

8. Erfindung nach Anspruch 1, wobei die ebenenverschobene Vorrichtung ein Mikrospiegel ist.

9. Erfindung nach Anspruch 1, wobei das Band ein Mikrogelenk ist.

10. Erfindung nach Anspruch 2, wobei ein zweites Ende der Bandstruktur an einem Ankerpunkt über der vergrabenen Oxidschicht angebracht ist und ein zweites Ende der ebenen verschobenen Vorrichtung nicht an der vergrabenen Oxidschicht angebracht ist.

Revendications

1. Assemblage micro-électromécanique (MEM, 18) comprenant :

   un dispositif hors du plan (22) formé en une couche de dispositif en silicium monocristallin d'un substrat d'isolant sur silicium (SOI) ; et
   une structure de ruban articulé (20) formée dans la couche de dispositif, où le dispositif hors du plan (22) et la structure de ruban (20) sont formés sous forme d'un assemblage intégré.

2. Invention selon la revendication 1, dans laquelle la couche de dispositif est formée sous forme d'une partie d'une pastille d'isolant sur silicium, comprenant au moins la couche de dispositif et une couche d'oxyde noyée.

3. Invention selon la revendication 1, dans laquelle la structure de ruban a au moins une largeur ou une épaisseur qui est inférieure à au moins la largeur ou l'épaisseur du dispositif hors du plan.

4. Invention selon la revendication 2, dans laquelle le dispositif hors du plan est fabriqué à partir d'une pastille d'isolant sur silicium qui a une épaisseur de couche de dispositif initiale uniforme.

5. Invention selon la revendication 1, dans laquelle la structure de ruban a une épaisseur comprise entre environ 400 nm et 600 nm, une largeur comprise entre 25 µm et 75 µm et une longueur comprise entre 70 µm et 210 µm.

6. Invention selon la revendication 1, dans laquelle le ruban est doté d'une intégrité mécanique qui permet l'application d'un couple mécanique de torsion latéral sur le dispositif hors du plan suffisant pour tordre le dispositif hors du plan à un angle de 90° ou plus à partir d'une position initiale tordue à un angle de 0°.

7. Invention selon la revendication 1, dans laquelle le ruban est doté d'une intégrité mécanique qui permet l'application d'un couple mécanique de soulèvement hors du plan pour soulever le dispositif hors du plan depuis un angle de 0° qui est dans le plan horizontal, jusqu'à un angle de 90° ou plus hors du plan horizontal.

8. Invention selon la revendication 1, dans laquelle le dispositif hors du plan est un micro-miroir.

9. Invention selon la revendication 1, dans laquelle le ruban est une micro-charnière.

10. Invention selon la revendication 2, dans laquelle une deuxième extrémité de la structure de ruban est fixée à un point d'encrage au-dessus de la couche d'oxyde noyée, et une deuxième extrémité du dispositif hors du plan est non fixée à la couche d'oxyde noyée.

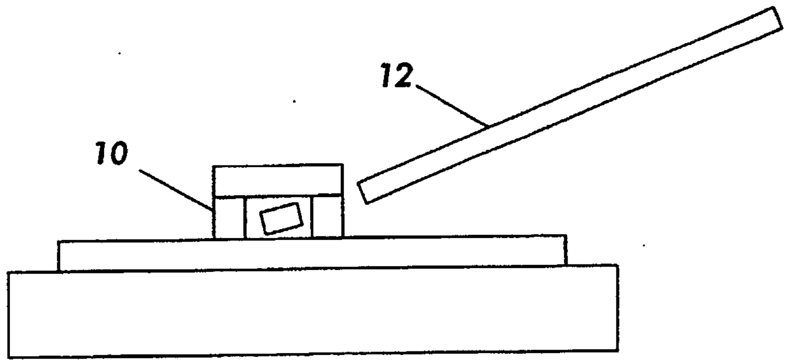

FIG. 1

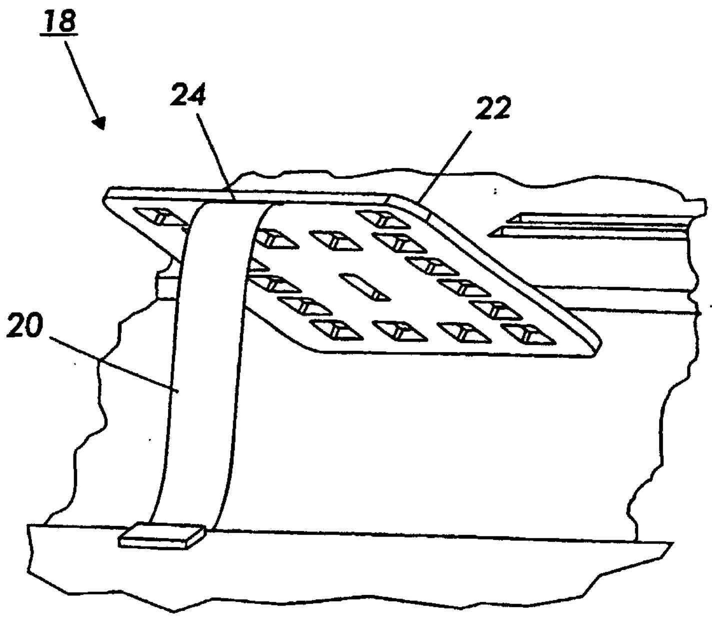

FIG. 2

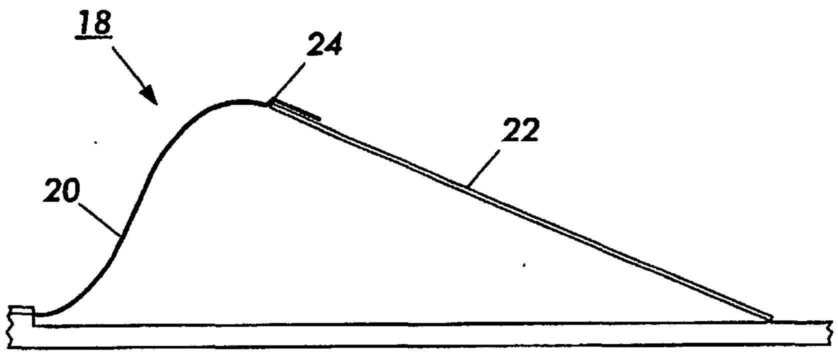

FIG. 3

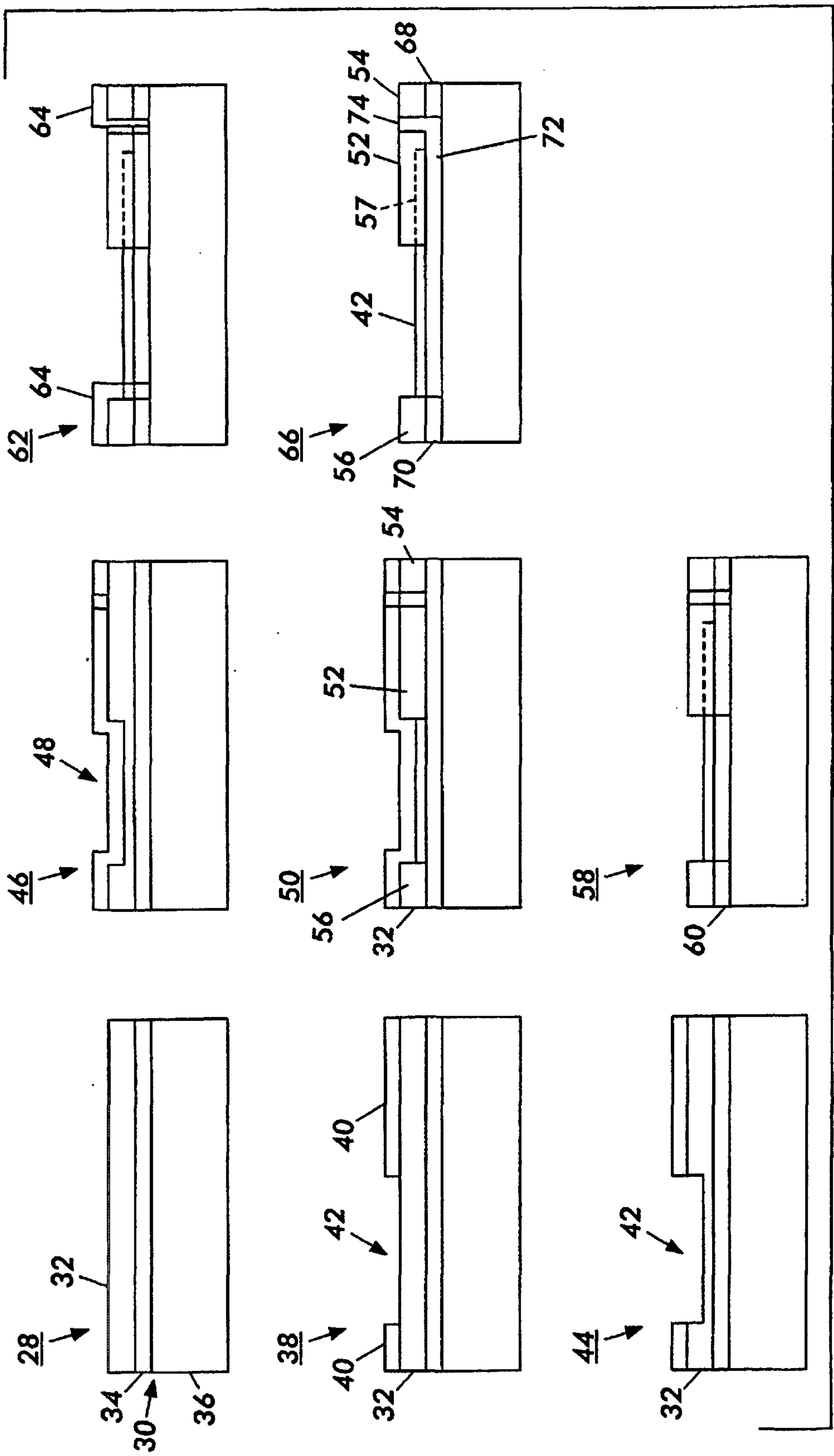

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FIG. 4

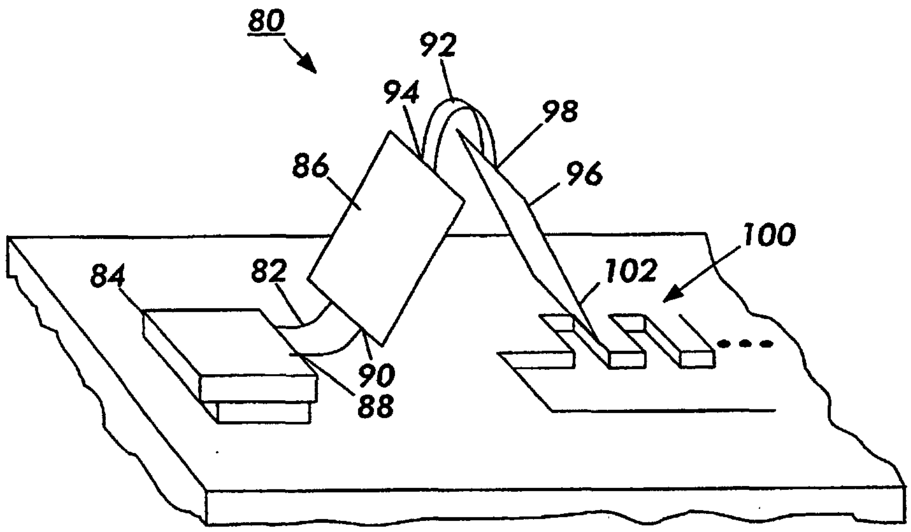

FIG. 5

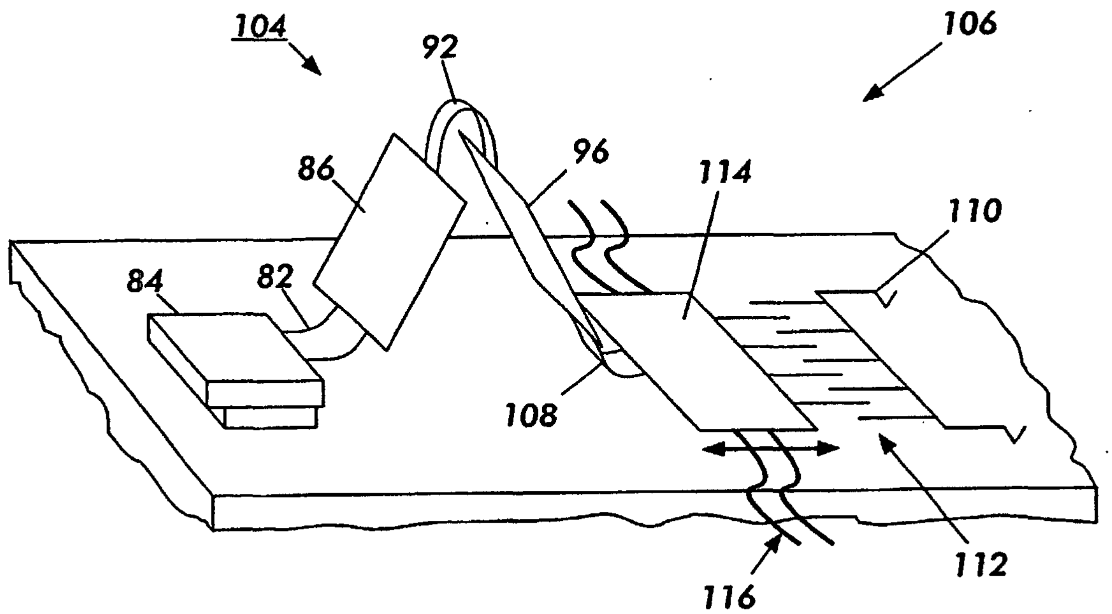

FIG. 6